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OCTOBER 1961

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Nathan Gerber
Joan M. Bartos

Department of the Army Project No. 503-03-001
Ordnance Management Structure Code No. 5010.11.814

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

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MEMORANDUM REPORT NO. 1376

NGerber/JMBartos/bjw
Aberdeen Proving Ground, Md.
October 1961

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ABSTRACT

Tables of similarity functions defining the flow field behind expanding cylindrical shock waves are presented here for γ=5/3 and γ=7/5. A brief discussion includes the differential equations and boundary conditions for these functions together with an analytical solution for them.

I DISCUSSION

Theoretical treatments have been given of the flow behind an expanding cylindrical shock wave produced by the instantaneous release of a finite amount of energy per unit length along a straight line of infinite extent.[1, 2, 3] These analyses lead to ordinary differential equations for 'similarity functions'.

The notation of reference 1 will be used here. The similarity assumptions introduced into the differential equations for unsteady cylindrical flow of a perfect gas are:

$$\begin{aligned} &\text{Density} && \rho/\rho_o = \psi(\eta) \quad ; \\ &\text{Flow Velocity} && u = A\phi(\eta)/R \quad ; \\ &\text{Pressure} && p/p_o = \left(\frac{\rho_o}{\gamma p_o}\right)A^2 f(\eta)/R^2 \quad , \end{aligned} \tag{1}$$

where R is the radius of the cylindrical shock wave; ρ_o and p_o are the density and pressure of the undisturbed gas ahead of the shock wave; $\eta = r/R$ is a non-dimensional variable; A is a constant (dependent on E, the energy released per unit length); and ψ, ϕ and f are functions of η only.

The following equations are obtained:

$$R\, dR/dt = A \qquad (t = \text{time}) \tag{2}$$

$$\begin{aligned} f' &= \frac{2\eta(\eta - \phi) + \gamma\phi^2}{f - (\eta - \phi)^2\psi} \quad \frac{(\psi f)}{\eta} \\ \phi' &= \frac{f' - \gamma\psi\phi}{\gamma\psi\,(\eta - \phi)} \\ \psi' &= \frac{(\eta\phi' + \phi)\,\psi}{(\eta - \phi)\,\eta} \end{aligned} \tag{3}$$

and

$$E = 2\pi\rho_o A^2 \int_0^1 \left[\frac{1}{\gamma(\gamma - 1)}\, f + \frac{1}{2}\,\psi\phi^2\right] \eta\, d\eta \tag{4}$$

The initial conditions for Equation (3) are (using strong shock assumption)

$$f(1) = 2\gamma/(\gamma + 1), \quad \psi(1) = (\gamma + 1)/(\gamma - 1), \quad \phi(1) = 2/(\gamma + 1), \tag{5}$$

where γ is the ratio of specific heats.

Equation (3) can be integrated numerically or else solved analytically by the implicit relationships given in [3] ; namely (with ϕ/η as the argument),

$$\begin{aligned} \eta &= \frac{K_1 \left| \frac{\phi}{\eta} - \frac{1}{\gamma} \right|^{(\gamma - 1)/(2\gamma)}}{\left| \frac{\phi}{\eta} \left(\frac{\phi}{\eta} - \frac{2}{\gamma} \right) \right|^{1/2}} \\ \psi &= \left[\frac{(\gamma - 1)}{2a} \eta \phi^2 \quad \frac{(\eta - \phi)^2}{(\eta - \gamma\phi)} \right]^{\frac{1}{\gamma - 2}} \\ f &= \frac{\gamma(\gamma - 1)}{2} \qquad \frac{\phi^2 (\eta - \phi)}{(\gamma\phi - \eta)} \quad \psi \end{aligned} \tag{6}$$

where $\underline{K_1}$ and $\underline{a}$ are determined by the conditions

$$\phi(\eta = 1) = 2/(\gamma + 1), \qquad \psi(\eta = 1) = (\gamma + 1)/(\gamma - 1) \tag{7}$$

Table I contains tabulations of ϕ, ψ and f as functions of η for $\gamma = 5/3$ (monatomic perfect gas). For this case

$$E = 2.257\ \rho_o A^2$$

For completeness, Table II is included with ϕ, ψ, and f for $\gamma = 1.4$, although tabulations of these functions appear in references 1, 2, and 3. (It should be noted that there are several numerical errors in reference 1.) For $\gamma = 1.4$

$$E = 3.94\ \rho_o A^2$$

The time - radial distance relation is

$$R = 1.154 \quad (E/\rho_o)^{1/4} \, t^{1/2}$$

for $\gamma = 5/3$, and

$$R = 1.004 \quad (E/\rho_o)^{1/4} \, t^{1/2}$$

for $\gamma = 7/5$.

Nathan Gerber

NATHAN GERBER

Joan M. Bartos

JOAN M. BARTOS

II REFERENCES

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2. Sakurai, A. On the Propagation and Structure of the Blast Wave, I. Jour. Phys. Soc. Japan, 8; 662 (1953).

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TABLE I

SIMILARITY FUNCTIONS FOR $\gamma = 5/3$--CYLINDRICAL BLAST

η	ϕ	ψ	f
1.000	.7500	4.000	1.2500
.995	.7438	3.850	1.2183
.990	.7378	3.700	1.1848
.985	.7310	3.555	1.1518
.98	.7248	3.417	1.1205
.97	.7117	3.148	1.0625
.96	.6992	2.914	1.0100
.95	.6868	2.703	.9620
.94	.6745	2.515	.9190
.93	.6622	2.347	.8787
.92	.6505	2.187	.8425
.91	.6390	2.040	.8090
.90	.6272	1.907	.7780
.88	.6052	1.670	.7225
.86	.5840	1.468	.6770
.84	.5638	1.300	.6378
.82	.5438	1.160	.6035
.80	.5250	1.032	.5738
.78	.5070	.916	.5495
.76	.4892	.814	.5285
.74	.4720	.728	.5100
.72	.4558	.657	.4945
.70	.4400	.592	.4802
.65	.4038	.447	.4548
.60	.3690	.340	.4365
.55	.3350	.260	.4237
.50	.3027	.187	.4150
.45	.2715	.135	.4095
.40	.2405	.093	.4058
.35	.2100	.063	.4040
.30	.1800	.040	.4028
.25	.1500	.023	.4022
.20	.1200	.012	.4020
.15	.0900	.006	.4018
.10	.0600	.003	.4018
.05	.0300	.001	.4018
.00	.0000	.000	.4018

This calculation made from Rouse's similarity solution. cf. reference 3.

TABLE II

SIMILARITY FUNCTIONS FOR γ = 7/5--CYLINDRICAL BLAST

η	f	ϕ	ψ
1.00	1.167	.833	6.000
.98	1.009	.804	4.578
.96	.890	.775	3.575
.94	.799	.748	2.845
.92	.728	.722	2.300
.90	.673	.698	1.884
.88	.629	.675	1.560
.86	.593	.653	1.303
.84	.564	.632	1.095
.82	.541	.612	.926
.80	.522	.593	.786
.78	.506	.575	.670
.76	.493	.557	.572
.74	.482	.540	.488
.72	.474	.524	.417
.70	.466	.508	.356
.68	.460	.492	.305
.66	.455	.476	.258
.64	.451	.461	.219
.62	.448	.446	.186
.60	.445	.431	.157
.50	.438	.360	.061
.40	.435	.288	.019
.30	.435	.215	.00
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